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TO BE ALIVE, WHAT IS IT?

THAT subtile, matter-quickening something we call life, in what does it consist?

The mere mention of its name conjures up a vision of all that is most marvellous in the sense-revealed universe. For the most part it is regarded as a mystery transcending naturalistic conception; as an alien influx into nature, baffling scientific interpretation. Philosophers, ancient and modern, have declared the vivification of the material composing living beings to be the work of an altogether exceptional, hyperphysical agency. And eminent scientists, satisfied that spontaneous generation nowhere occurs, have conjectured that the germ of life has meteorically descended on our planet from the skies.

It is true, physiologists, not long ago, entertained the hope of solving the problem of vitality by means of the hypothesis of atomic mechanics. It has, however, become more and more evident that vital processes, even of the simplest kind, are not of the mechanical order. But, if not through mechanical agency, through atomic push and counterpush, how then are the activities, the purposive movements of life effected?

The scientific spirit revolts against the facile subterfuge of attributing the occurrence of any obscure event in nature to the miraculous intervention of any kind of extraneous power. It can find restful satisfaction in no sort of conflict between incommensurable agencies. It irresistibly urges towards unification, towards a monistic interpretation. The ever-present intuition, guiding and inspiring scientific investigation, is the firm belief that nature is all-embracing, that all her phenomena without exception are interdependently connected, are forming part of one all-comprising cosmos.

This steadfastly in mind, the attempt shall here be made, first to gain a scientifically justified and logically consistent physical basis, upon which a naturalistic conception of vitality can be reared; and, then, to show to what special physical conditions vital activities and vital organisation owe their existence.

THE PHYSICAL BASIS.

However inscrutable the vivification of lifeless stuff may appear, the rest of nature, things inanimate, have in a manner become intelligible to us. Thunder and lightning, earthquakes and plagues, are no longer regarded as wilful visitations of living Gods; of Indra or Jahve, of Zeus or Thor, of Ahriman or Jove. We view them as necessary outcomes of the present order of nature. And, therewith, they have lost most of their terrorising influence over us. We can tell whence the wind cometh and whither it goeth; and do not stand confounded before the birth of the storm-laden clouds. We know what "shakes the old beldame earth, and topples steeples and moss-grown towers." And we do not shrink from waging war against all manner of pestiferous scourges. No such portentous heart-beats, as beset the mediæval conscience of Petrarch, oppress us when we ascend heaven-scaling Alps, and behold at our feet the glory of the far-stretching, sunlit landscape. To us the woods bear a familiar aspect. No satyrs or fauns, no mischievous elfs or gnomes haunt their grateful shades. Overhead the sun sheds his majestic light more reliably by far than when all-seeing Helios drove him along. And universal gravitation holds the starry host more trustfully within ordered cycles than could any divine volition of their own.

Our dread of outside nature seems to diminish in measure as we become convinced that nothing vivifies it from within; that its divers constituents, its heaven and earth, its winds and waters, its stocks and stones, are in no way volitionally actuated. The sense-apparent properties of things once probed, we fear not that they will turn upon us with untoward powers. Instead of cringing before their hidden terrors, we proudly move among them as masters, controlling and utilising their sundry efficiencies. Unlike our savage ancestors, whose religion consisted chiefly in attempts at propitiating malignant influences abroad, we snugly-settled optimists have almost come to believe with Candide that this is indeed the best and most benignant of worlds.

Yet such seemingly close familiarity with the outside universe, and the apparent recognition of its nature, is after all but a fond illusion. All things have in truth become far more enigmatical, far more foreign to our understanding, since we fail to discover any analogy between inanimate activities and our own volitional performances. The saying of Socrates, that physical nature must ever remain incomprehensible to us, while we are competent to recognise our own mental and moral being, while—as he expressed it—the command of the Delphian god, "Know thyself," could and should be obeyed; this agnostic declaration on the part of the wisest of ancients regarding the physical side of nature, may after all not be so completely off the mark as most scientists of the present day would be inclined to acknowledge.

Gravitation, though its mode of occurrence is mathematically precise, acts really by force of something not remotely so well known to us as our own volition. The evolutional drift of the endless preparatory stages of elaboration through which the original stuff of our planet has passed before it became fit to serve as a habitation for living beings; this physical becoming is infinitely less intelligible than the process by which we ourselves make things subserve remote ends. The forces that actuate and shape material things from within are indeed incommensurable with the activity by which we seize upon them from without, to put their given efficiencies to intelligent uses.

Our comprehension of matter and its forces, vicarious or symbolical as it necessarily is, is moreover limited by the scope of our sense-informed imagination. The astoundingly sensitive response of a lifeless wire to the lightning speed of the electrical influx, and to its slightest minutiæ, is incomparably more perplexing to our conception, than, for instance, the rate of the propagation of the immensely more sluggish current of activity along our living nerves.

Furthermore, it is obviously only by dint of co-natural congruency and sympathy that we come to understand the inwardness of any thing or event whatever. We are well enough aware what it inwardly means when some other living being is seen to be in an angry or in a pleased mood, to be laughing or weeping. But who can grasp with co-natural sympathy the inward meaning, the motive intention of a cyclone or an earthquake, of shining light or falling snow, of physical or chemical activity? We generally rest satisfied when we have ascertained that it all occurs in accordance with definite "laws"; that it all forms part of the "mechanism of nature," of a rigorous concatenation of "causes and effects."

But what scientist has the slightest inkling of that which really constitutes inanimate or physical activity? He calls it force, and believes it is something that can move or energise matter. He calls it energy, and imagines that this immaterial essence of activity—in truth a mere mental abstraction—can slide from one material compound into another, assuming protean modes of appearance. At times he calls it motion, without realising that "motion" is only a perceptual sign of ours for all manner of activities we have no power of intellectually assimilating.

In this helpless predicament some are bold enough to cut the knot by asserting that it is volition which here also is imparting motion to lifeless matter; moving it—as some maintain—from within as will of its own; or—as others will have it—from without by force of the will of some *deus ex machina.* But what legitimate analogy can be found between the conscious, aimfully directed movements of our appropriately organised living body, and the evidently unconscious, purposeless motions of things in which no perceptible sign of animation or volitional direction can be detected?

And if our intellect is powerless to assimilate inanimate or physical activity with what it is cognisant of as animated or volitional activity, our senses fail to yield us adequate information regarding even the effects of such physical activity. We offer our sundry sensibilities as delicately graded reagents to the sense-affecting agents of the outside world. How marvellous the definiteness of our vision, its close inspection and distant reach, its refined distinction of shades and colors! And what a world of sounds is revealed to our hearing! How sensitive our feeling to grades of heat and cold, to degrees of resistance and weight! How discriminative our tasting and smelling! Yet lifeless glass-lenses, photographic plates, vibrating membranes, thermometers, scales, and chemical reagents innumerable outdo us in the recording and penetration of distinctions obtaining in the material universe. Who can tell what marvels of nature may be taking place beyond the reach of our living senses, even when supplemented by artifical aids? How utterly sense-transcending, for instance, the intimate constitution of bodies, or the real properties of the interstellar medium that transmits to us life-supporting heat and light, and is the bearer of that strange, terrific power we have learned to harness in batteries and dynamos, without the least conception of its real nature.

In order to realise what kind of world it is, in which we move and have our being, it is well not only to live in the light of knowledge attained, but at times also to remind ourselves of regions outlying and unrevealed.

The activities, by whose agency is fashioned in extra-conscious existence that marvellous piece of workmanship we call physical nature, are at least to some extent immediately known to us by means of their effects on our own being, by means of their sense-affecting efficiencies. But of what nature is the existent that proves itself thus active? Activity cannot possibly be self-sustained. It must be the activity of something. Even in Wonderland the "grin" cannot be fancied without the "cat." Just as little can we conceive activity existing and persisting without an acting agent.

What then has our present science to say about this irreducible something which is the acting agent in nature? It generally teaches that the physical universe consists of matter and force; or, more technically expressed, of masses possessing kinetic or potential energy; that is of a statical and a dynamical principle, of a permanent existent serving as vehicle to varying modes of activity, manifest as so many modes of motion or commotion.

Now it is clear, that what affects our senses are only so many modes of activity of that which is active. Peculiar modes of activity affect our sense of touch, other modes our sense of sight, others again our sense of hearing, and so on. And it is obviously only by force of these sundry modes of activity that the acting agents of the physical world make their existence and peculiarities known to us. We cannot rightly say that the existing agents are unknown, for we actually know them by dint of the effects they work in us through their characteristic activities; activities which are essential to their existence, which in fact constitute them specific existents distinguishable from one another. Moreover, the various modes of our sensibility, through which on stimulation we recognise physical existents, are themselves phylogenetically inwrought effects of their activities; or, more correctly perhaps, they are reactive responses attuned to their divers modes of stimulation.

Still the activities are not themselves the acting agents; the properties of the substance not themselves that substance. We cannot rest satisfied with mere physical phenomenism. We are naturally and forcibly led to believe that activities emanate from efficient existents, or so-called bodies. And this because the presence of what by means of our percepts we infer to be such induces changes in other suchwise inferred bodies, and in ourselves as sole consciously realising reagent.

Right here, however, the current conception, that it is the *actually perceived* universe which consists of force-endowed bodies, or masses possessing kinetic or potential energy; this conception gives rise to a knot of perplexities difficult to disentangle. It is clear, as already stated, that all we perceive of physical nature, all its so-called objects, together with their changes, are really effects induced in us solely by its activities. The entire perception, so long as it lasts, is out and out a stimulated effect of a group of unremitting activities. There is nothing induring, nothing whatever substantial in it. Yet we are wont to detach from this perceptual group of activity-induced effects a comparatively changeless component which we then wrongly conceive as being itself a material body or substance, constituting it an unchangeable vehicle for less stable and subsiding components of the perceived activities.

When the percept "gold," for instance, is awakened in us by a definite group of physical activities, we generally pick out some of the less changeable of these activities, such as resistance or inertia-force, weight or gravity-force, degree of cohesive force, specific modes of chemical force or reaction, and so on. These less changeable activities we install as the permanent substance "gold," while we allow less stable activities, mainly degrees of molar and molecular motion, to pass over into other physical bodies in the form of what we call energy, an immaterial something deemed to be convertible into other modes of this same immaterial something.

This perceptual and therewith mentally symbolical realisation of extra-conscious things and events, constitutes the principal puzzle encountered by scientific interpretation. Physical science itself, when it goes cautiously to work, likewise only *infers* the existence of bodies, or permanent existents. And this solely by dint of mutual relations obtaining between perceptible activities. When, moreover, it seeks to rid itself of all merely inferred existence, it is apt to become reduced to mere objective phenomenism, and at last to nothing but perceptual space and time-relations. Such pure phenomenism is then meant to be utterly devoid of realistic inferences, devoid of substantiality and efficacy, of actual matter and force.

Yet, however masked, there persist, even here, in mathematical physics of the most abstract kind, inevasibly, the old irreducible realistic postulates, the common-sense assumption of force-endowed existents. For those physical percepts, generally called bodies for the sake of intelligibility, whatever space, large or small, they may occupy in perception or conception, are here necessarily inferred to act upon one another in specific ways, so as to induce definite changes in their space and time-relations. Without this realistic assumption of force-endowed existents,—perceptual phenomena conceived as such in this instance,—physical phenomenism would be incapable of establishing any relation whatever between the perceived changes in the position and velocity of percepts, which changes constitute the sole subject-matter of its investigation.

And it need hardly be mentioned that this attribution of efficacy and therewith substantiality to mere transitory percepts, which in fact and also according to the adopted theory are wholly unsubstantial and forceless ; that such procedure involves physical phenomenism in outright contradictions.

Is it not far more justifiable to assume at once that the feeling of effort and resistance we experience when endeavoring to act upon what in conscious representation appears as an immaterial and forceless percept, corresponds in reality to a force and counter-force exerted by physical existents subsisting outside our consciousness? And as our own efficient being in this experience belongs to physical nature as well as other existents acted upon and reacting, we may legitimately infer that all physical existents have power to act upon one another so as to induce changes in their respective dispositions and constitutions.

Physical science, of a less subtile kind than pure phenomenism, is wont to start frankly with the realistic common-sense assumptions. It conceives, however, the physical existents and the activities they display, as two separable factors in nature. In so doing it runs itself into wholly contradictory conclusions. The physical world is thus held to consist, not of force exerting agents, but of inert, force-driven particles ; not of existents possessing inherent energy, but of such possessed by energy *ab extra.* This modern conception of modes of energy being transferable and interconvertible, when meant to express an actual fact in nature, stands seriously in the way of a correct interpretation of physical occurrences. It logically reduces the world-material, that forms the endlessly diversified and power-endowed universe, to an utterly passive *caput mortuum*, to a mere space-occupying, qualitatively indifferent vehicle of activities and qualities, believed to be imparted to it by being simply knocked about from without by an immaterial factotum, called energy.

In the whole range of thought there exists no more fanciful belief than that which makes so utterly inconceivable an abstraction as pure energy or motion detach itself from a moving mass to seize upon another mass which it thereby energises.

That there obtains in nature a strict reciprocal equivalence, or invariable quantitative relation, between causes and effects, between changes occurring in interdependent groups of physical existents, of this there can be no doubt. But these changes are one and all the outcome of powers inherent in the manifesting agents, and nowise merely wrought upon them from without.

All physical existents of which nature is composed tend to equilibration of their respective powers or energies. This process of equilibration never deviates from a strictly quantitative as well as qualitative correlation of the changes through which it is attained. The quantitative aspect of these changes is conceived as equivalence, however qualitatively disparate they may prove to be. So much mechanical impact of physical existents induces exactly so much heat-commotion.

Nature is not composed of indestructible matter on one side, and indestructible energy on the other; but of perceptually distinguishable physical existents subsisting under strictly interdependent relations to one another, quantitatively and qualitatively.

We become consciously aware of physical existents solely by their sundry characteristic activities stimulating our senses. And just as certain as these activities merely *stimulate* our senses, nowise passing over into our being, just as certain do these same activities merely *stimulate* changes in other physical compounds without passing over into them.

The greatest triumph of the purely mechanical theory is supposed to have been achieved in the kinetic theory of gases. Yet all the astounding velocity attributed to gas-molecules would speedily come to a standstill, if they were not themselves held to be intrinsically endowed with the master-spring that keeps it all going. For in the words of Newton, "if two equal bodies meet directly in vacuo, they will by the laws of motion stop where they met, and lose all their motion and remain at rest, unless they be elastic and receive new motion from their spring."

It is solely by theoretically endowing the gas molecules with perfect elasticity, that is with an inexhaustible intrinsic power, mechanically equivalent to the entire kinetic energy with which they ever so often and ever so forcibly collide, that the physical phenomena displayed by gases can be mechanically interpreted. Here the kinetic energy lost by impact is ever newly reproduced by a force inherent in the molecules themselves. Such kinetic energy, therefore, instead of being externally imparted to them, is actually an outcome of their own intimate and inalienable nature.[1]

This state of things being considered as obtaining between the molecules of gases, there is no reason why it should not likewise obtain between solid masses, made up of the same molecules. Therefore, on mechanical impact of two solid bodies the resulting commotion of their constituent particles, felt by us as heat, is just as much an outcome of stimulated elasticity, as was held to be the case in the gaseous state. Only here cohesion acts as a counterforce.

As, even in these foremost examples of mechanical activity, there occurs evidently no actual transmission and conversion of energy, but only equivalent modes of action and counteraction, it stands to reason that this holds good all the more regarding other modes of activity, such as gravitation, cohesion, chemical affinity, magnetism, and so on.

We shall never come to appreciate the wondrous potencies and potentialities inherent in physical existents, unless we relinquish the conception of transmitted and interconvertible modes of energy. All percepts, which constitute for us the characteristics of definite physical existents and their activities under definite conditions, will reappear whenever these existents are brought under the same conditions. This involves the conservation of the physical substratum as well as the conservation of its energies. Or, rather, it reveals its infallible specific constitution and powers under definite conditions.

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[1] That which goes by the name of kinetic energy is perhaps the strangest of all modes of energy. That a physical existent should be able to acquire unlimited amounts of power to change the state and constitution of other physical existents merely by traversing more space in less time—space and time being conceived as themselves utterly forceless—this fact more than any other brings home to us how much of essential efficiency in nature remains unexplained.

How can an activity, an effect-producing efficiency, impressed upon a mass, impressed upon it without working any change whatever in its own intrinsic condition, how can it become a function of forceless space and time ? This would seem to indicate that what in our perception appears as forceless, empty space corresponds in extra-conscious reality to a force-endowed medium, whose actual existence is indeed made evident by the sundry modes of radiant energy.

That all modes of unequiliberated activity manifest themselves to us as so many modes of motion or displacement, is due to the fact that our perceptual sign for every kind of physical change takes the form of motion or commotion of our percepts. It is, therefore, obviously erroneous to conclude that these perceptual modes of motion are the cause of the changes occurring in physical existents. And it is erroneous also to conclude that the activities of physical existents which we perceptually realise as motions are themselves only motions.

When a chemical compound is formed by combination of elements, the process is perceptually realised by us as a commotion among the combining particles. But from the newly acquired properties of the compound, revealed in roundabout ways to our different senses, we rightly infer that specific energies appertaining to the combining substances have been here at work, while we were merely perceiving definite modes of commotion.

The various considerations here brought forward, and many more not here touched upon, allow us to conclude, that changes occurring in and among physical existents, changes perceived by us as motions or commotions of the percepts aroused by their sense-stimulating activities ; that these changes are wrought by specific efficiencies belonging to their own intimate nature.

VITALITY AND ORGANISATION.[1]

The general remarks of the previous section were called for in order to establish a position from which a correct co-natural interpretation of "life" may be attained. Scientists have been on the wrong track when they supposed that vital activities could be correlated with the activities of lifeless nature, by simply applying to them the laws of mechanically induced motions.[1]

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[1] The views here expressed are the result of a study of primitive forms of life, carried on during a number of years.

To arrive at a unitary view of nature, we have, on the contrary, to regard all activities, whether displayed by living or by lifeless existents, as the result of the action and reaction of their own specific energies.[2]

Yet even to casual observation there exists no greater contrast among the constituent objects of nature than that witnessed between living and lifeless things. It is above all the vital phenomenon of self-movement which strikes the sense as something differing altogether from changes undergone by lifeless objects. These seem to be moved only when externally pushed or pulled, while the motions of living bodies seem to be actuated by a power inherent in themselves.

On closer examination the contrast between these two modes of bodily existence becomes even more profoundly marked. The structure of living beings is found to be framed throughout for the attainment of definite ends connected with their own particular welfare. And it is fashioned, moreover, into organs of interaction with special objects and agencies of the outside world, through which these are likewise rendered subservient to the needs and purposes of such beings as are endowed with life. Lifeless bodies, on the other hand, are mere inorganic aggregates of particles, whose structure is not disposed in a way to conduce to the welfare of the body as an integrant being. Nor are the relations of interaction between inorganic bodies and their surroundings such as result in transforming constituents of the latter into means for satisfying the special wants and aims of the former.

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[1] Having from my biological standpoint for many years argued against the purely mechanical interpretation, I rejoice to find the objections I have urged corroborated by a professional physicist of the highest standing. Professor Mach, in his remarkably lucid *Science of Mechanics*, translated in a masterly manner by Mr. Thomas J. McCormack, and beautifully published by The Open Court Publishing Company, remarks: "Purely mechanical phenomena do not exist. With dynamical results are always associated thermal, magnetic, electric, and chemical phenomena, and the former are always modified in proportion as the latter are asserted. On the other hand, thermal, magnetic, electric, and chemical conditions also can produce motions. Purely mechanical phenomena, accordingly, are abstractions.

"The view that makes mechanics the basis of the remaining branches of physics, and explains all physical phenomena by mechanical ideas, is, in our judgment, a prejudice." (Chap. V.)

[2] The recognition of specific energies in opposition to Lewes's and Wundt's view of "functional indifference" was urged by the present writer in *Mind*, Vol. V, 1880, under the title "The Dependence of Quality on Specific Energies."

The distinction between living and lifeless bodies extends furthermore and deeper still to the relation in which their minutest constituent elements stand to one another. In living beings the ultimate elements of their structure are not only throughout interdependently connected by specific bonds of union called chemical, but they are, moreover, involved in a definite cycle of changes controlled by the nature and activity of the living individual as an indiscerptible entity. Lifeless bodies, on the contrary, consist of a multitude of separate non-interdependent chemical units, forming a more or less coherent aggregate held together by bonds of union called physical. And whatever displacements their constituent particles may suffer are nowise actuated nor controlled by the nature of the body as a whole. In fact, a living being may be looked upon as one single vast and complex chemical vortex. While lifeless bodies are more or less bulky conglomerates of incomparably less complex molecules.

But the most remarkable of all contrasts obtaining between living and lifeless bodies has yet to be mentioned. A living being begins its existence as a mere rudiment of itself, as a so-called germ. This all but shapeless germ, by a most specific cycle of intrinsically controlled changes, assisted by assimilable matter and other agencies of its environment, develops gradually into a full-fashioned individual, reproducing in rejuvenated form an exact copy of the adult organism from which it was derived. It grows by developmental stages from ovular and embryonic beginnings to perfect stature. It is true a crystal immersed in a solution of its own material may, by a figure of speech, be likewise said to grow. But it does so not by a process of intrinsic assimilation of complemental material, but simply by external accretion of the same material of which it is itself composed. And this its so-called growth leads in no way to the gradual development of a specifically organised form, but only to an enlargement of the same initial shape.

Another and culminating distinction between living and lifeless bodies widens still more the distance by which they are divided. Biological science leaves no doubt that life on our planet was first manifested by elementary beings whose structure showed no trace of morphological organisation. And it is from such primitive beings that the highest organisms now extant are the marvellously developed descendants. The sundry inorganic substances that enter into the constitution of our planet gained likewise their present molecular constitution gradually under changing cosmical and geological conditions. But the growing complexity of their structure was not, as in living beings, genealogically transmitted from individual compounds to individual offspring. The phenomenon of procreation has no analogous counterpart in lifeless nature.

The scientific problem of life offers thus difficulties transcending immeasurably those encountered in the interpretation of inorganic phenomena. What in verity can be the nature of this most intimate, yet least understood fact of vivification?—this intangible something whose formative potency draws to itself stray stuff from the visible world, coercing it into significant organic arrangement and prescient aimful activity; illuminating, moreover, its tiny air and dust-built habitation with the glow of emotive affections, and a vast expanse of world-revealing visions?

Here again, as in inorganic science, we have no other than sense-awakened data upon which to ground our explanation. Vital phenomena, their morphological appearance and physiological bearings, are all only sense-revealed. And it is almost altogether upon a foundation of nothing but visual percepts, consisting of mere shapes, shades, and colors and their changes, that we have to frame our conception of the astonishingly complex nature of organic beings and their vital activities.

With such eminently indirect and fractional data for interpretation, it seems obvious that a close study of the most primitive, least intricate forms of life, holds out the best hope of arriving at a correct view of the nature of life in general.

When we have under observation living beings of all but homogeneous appearance, possessing no specified organs, no morphological differentiations, and yet performing all essential vital functions, nutritive and depurative, motor and sensory, and moreover growing and procreating ; when we have all these vital marvels taking place under our very eyes in their simplest and most transparent aspect ; it would seem, that, if the mystery of vitality can ever be solved, it will be by gaining an understanding of the intimate molecular processes that give rise to these fundamental vital activities.

We have before us a substance consisting out and out of well-known inorganic elements, that, unlike other combinations of these same elements, displays those wondrous phenomena which distinguish so characteristically living beings from lifeless things. To what sort of influence does it owe its singular endowments? It is the same influence through which we also are alive.

Has, then, perchance some superefficient power, unrevealed in lifeless nature, seized upon those inorganic elements from without, forcing them to fall into highly intricate combinations and modes of activity, altogether foreign and antagonistic to their own propensities ?

Or has it rather been by dint of potentialities inherent in themselves, that, through gradual, toilful composition, these elements have come to form combinations of such intricate nature as are found to display that peculiar cycle of interdependent activities in which life is seen to consist ?

In closely watching the least complex beings now extant, such, namely, as display amœboid movements, the physical aspect of vitality discloses itself as a definite, interdependent cycle of molecular occurrences. In selecting suitable specimens it is not difficult to interpret the phenomena under view. The flowing-out from the substance of the protoplasmic individual of more or less numerous, more or less elongated and attenuated processes, or pseudopodia as they are sometimes called, alternating after the lapse of more or less time with their shrinking and reincorporation ; this simple occurrence of partial expansion and contraction, ever uniformly reiterated, constitutes the fundamental twofold, yet indivisible, action in which vitality essentially consists. All other vital functions are subservient to this central see-saw movement. And it will be shown that its developmental elaboration draws with it the differentiation of the protoplasmic substance into specifically formed and specifically acting tissues and organs.

Our task then is to frame from the data here given a scientific conception of the intimate molecular occurrences that determine this particular activity in which vitality consists. Furthermore to discover the conditions which in the course of organic elaboration give rise to the differentiation and position of the principal tissues and organs of highly developed organisms.

First of all let us ascertain what has happened when a process, vigorously pushed out from the substance of an amœba, is gradually arrested in its onward course, beginning thereupon to shrink within itself, and ending in being reincorporated. In order to witness typical and most instructive cases of this occurrence, such amœboid beings have to be selected as push out slowly long and broad processes.

In attentively observing such cases (Fig. 1) it becomes evident that the shrinking of the process is the work of chemical disintegration. It begins at the surface of contact with the medium and extends gradually, and more or less rapidly and completely, towards the centre, or rather the axis of the protoplasmic cone or cylinder. This is clearly evidenced, first by the slackening flow of the granules embedded in the substance near the surface, and then in that portion of the hyaline substratum brought into contact with the medium becoming itself granular. In

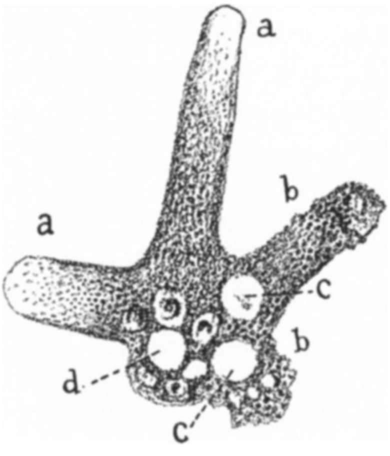

FIG. 1.—AN AMŒBA WITH LONG AND BROAD PROCESSES.

a a. Outflowing processes.
b b. Shrinking processes.
c c. Depurative vesicles gathering the fluid products of functional decomposition.
d. Depurative vesicle gathering the fluid products of nutritive decomposition.

favorable specimens it can be easily seen that a process of this kind owes its elongated shape to the stagnating surface forming a lengthening tube, through which the central, still fluent material issues farther and farther into the medium. The proof that the change here observed is in fact the work of chemical disintegration, and not of mere physical modification, is visibly given by vesicles forming within the disintegrating substance, in which are gathered the effete products of decomposition, presently seen to be eliminated.

The influences that are causing this chemical disintegration are readily detected. Any sort of contact or external stimulus tends to decompose more or less profoundly the highly complex and therewith explosive constitution of the protoplasm. During formation of a process an expanding surface is offered to the stimulating influences of the medium, and the ensuing disintegration, accompanied by shrinking or so-called contraction, is obviously the effect of these influences. By means of artificial or supernormal stimulation the shrinking may be accelerated and heightened. Stimulation on the part of the medium may, on the other hand, be called normal or functional, when it does not decompose the protoplasmic substance all too profoundly, that is, beyond easy restitution. Such normal stimulation is indeed an essential and indispensable condition of vital activity. The consequent disintegration of the stimulated substance forms the retrograde or contractile phase of the fundamental vital function. And it was on account of this salient phenomenon of shrinking on stimulation that the living substance has been predominantly regarded as a contractile substance. Furthermore, "irritability" on stimulation, or "sensibility" in case the effect of stimulation was believed to be felt, used to be looked upon as the chief characteristics of life.

The study of protoplasmic individuals teaches, however, that the immediate effect of stimulation gives rise only to the retrograde or negative phase of vital activity. In order that the unitary movement in which life consists may be completed, it has to be complemented by the restitutive, positive phase.

Now as the shrinking or contractile phase of protoplasmic activity proves to be the outcome of chemical disintegration, it is legitimate to infer that the complemental phase of re-expansion must be the work of chemical reintegration. And this is obviously the case.

Different stages in the elaboration of the living substance manifest themselves through the divers ways in which the fundamental vital activity is carried on, and also through the sundry forms which amœboid individuals in consequence assume. There are specimens which push out long and slender processes, whose substance offers so little restitutive resistance to the disintegrating influences of the medium as to become quickly stagnated through and through, remaining thus often for hours together exteriorised and apparently deadened. Other specimens with just as slender and long processes manage to restitute their substance rapidly enough to be capable of maintaining partially and for a considerable time their fluent state in spite of exposure to the disintegrating influences. It is this more or less rapid play of alternating disintegration and reintegration which imparts to the protoplasm its pulse of life, which constitutes it a living substance.

We have seen by what means protoplasmic disintegration is brought about. How, then, is its re-integration effected?

Let us keep our eye on the exteriorised and seemingly deadened processes of the protoplasmic star (Fig. 2). All sort of stray stuff is promiscuously drifted through its rays. Among numberless particles of foreign matter coming in contact with them only a few are attracted and retained. Through adhesion of many such attracted particles the sharp outline of the processes becomes gradually serrated. Their material undergoes thus progressive restitution through chemical union with this foreign complemental stuff, remelting and shrinking within itself. Several processes in this state of liquefaction meet, coalesce, and form eventually a globule which is drawn into the body, constituting there one of the meshes of the reticulated structure that makes up the outer layer of the little creature's frame. At times a large body, fit for assimilation, gets caught between the rays, which in consequence rapidly dissolve, shrinking so as to form a globule enclosing the foreign body.

Here in this least complicated and undisguised example the secret of nutrition, and therewith the nature of vital assimilation, so obscure in highly developed organisms, is clearly revealed. Food serves simply as complemental or restitutive material. Its assimilation consists in appropriately filling the chemical gap caused by functional disintegration. The force that underlies this vital reintegration is the avidity of the functionally deteriorated protoplasm to restitute its chemical integrity. A highly complex organic substance suffers partial decomposition. Thereupon, by force of its own most specific affinities, it reintegrates itself with complemental material.

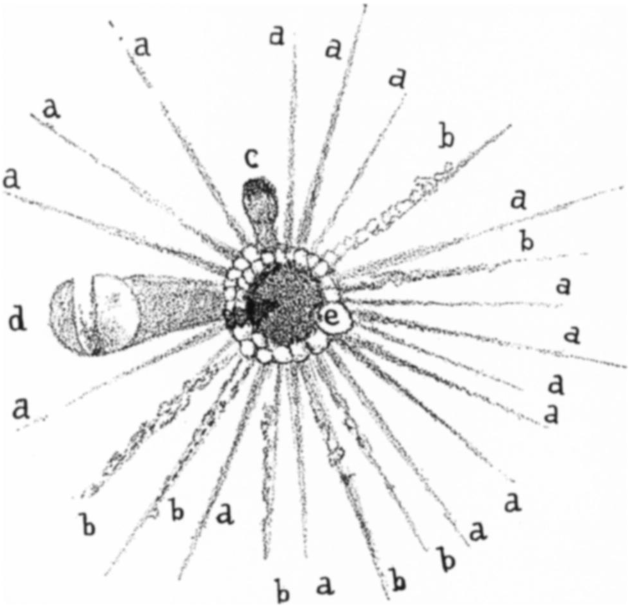

FIG. 2. STELLATE PROTOZOÖN OF WHICH ONLY THE RAYS IN THE FOCUSSED PLANE ARE VISIBLE.

a a. Sharply outlined rays.
b b. Serrated rays with adherent complemental material.
c. A shrinking ray forming a nutritive corpuscle.
d. Foreign organism round which many rays have coalesced, forming a large nutritive corpuscle.
e. A depurative vesicle eliminating periodically fluid products of decomposition.
f. Undigested residue of food [dark spot at the base of d].

Add to this, that the waste products of decomposition are eliminated, and you have the threefold, and yet unitary, activity, which in the course of development gives rise to the differentiation of the complex organism into three main sets of tissues; the first carrying on the functional play with the medium, the second ministering to nutritive restitution, and the third to depurative elimination.

The study of gradations of low forms of life indicates unmistakably that the ectoderm of highly developed organisms represents the morphological elaboration of the relations of the living substance to the sundry stimulating influences of the medium. The entodermic organs constitute the structural fixation of the relations of the living substance to its nutritive or restitutive resources. The office of the depurative organs is, first, to eliminate the waste products of ectodermic function, and then also those of the nutritive function.

To gain an understanding of vitality and organisation, it has to be steadfastly borne in mind, that however intricately differentiated into organs, tissues, and components of tissues an organism may appear, its structure is out and out the visible substratum of this manifoldly related, and yet indiscerptible, activity. It is this indivisibly correlated threefold disposition of the unitary movement of life, that governs organisation from its first beginnings to its most complex development.

It stands to reason that the development of the life of dynamical relations with the medium, or what amounts to the same thing, the development of its structural embodiment in the ectoderm : in neural tissue, muscular substance and sensory organs ; that this development calls for more and more highly elaborated restitutive material. While, on the other hand, the growing incongruity of the raw material furnished by the medium for restitutive purposes necessitates a more and more complex series of preparatory processes carried on by means of the elaboration of the entodermic organs : the digesting, blood-preparing, and blood-distributing organs. The depurative organs, meanwhile, lungs, kindneys, and the rest of them, or their more primitive substitutes, keep pace with the general structural elaboration.

The entire developmental process is evidently controlled by the functional play of the organism with its medium. This fundamental process of vital disintegration and reintegration involves nutrition and depuration.

After interpreting vital activity in the simplest manner from directly given data, some more indirect conjectures may be allowed. First, as to the probable origin of life on our planet; and second, as to the general conditions that have conduced to its structural development.

Wherever a complex molecule, formed during the chemical elaboration of our planetary material, suffered slightest disintegration, that is, loss of any of its constituent elements, and was thereupon able to reintegrate itself by means of combination with complemental elements offered by the medium, there life had its beginning. For vitality consists essentially in alternate disintegration and reintegration. No doubt the original molecule that first displayed this primitive vital activity was of an incomparably less complex nature than any vital molecule now extant. But of whatever primitive kind, its alternate disintegration and reintegration raised it from the sphere of lifeless existence into that of living activity.

And now what are the conditions that have resulted in molecular and structural development? Amœboid activity is seen to consist essentially in offering ever-renewed processes to the disintegrating influences of the medium. It may be legitimately conjectured that the stimulating influences have induced, and are still inducing, a specific elaboration of the living substance. By splitting off a definite molecule, they will determine to some extent its reintegration. The pre-established direction of its intrinsic affinities, though marvellously specific, suffers some infinitesimal change through the molecular disturbance generated on each concussion. Instead of restoring with absolute precision its former integrity, the protoplasm incorporates a molecule slightly differing from the one it lost. We know that in plants organic compounds are built up by an analogous process. For elements split off by stimulation there are substituted other elements which go to make up higher compounds than those previously decomposed. Disintegration affords the stimulus whereupon, by dint of affinitive substitution, higher integration takes place. In the laboratory higher compounds are likewise built up on this plan of gradual substitution.

It is, therefore, not far-fetched to conjecture that the highly wrought constitution of protoplasm has been most gradually elaborated by a similar process. And is it not highly probable that the structures of the ectoderm have been elaborated and differentiated through interaction and in accord with the diverse stimulating influences, that actually determine the specific outcome of their functional activity?

It will be well to consider for a moment how radically distinguished living substance really is from non-living material, however highly constituted this may be. The substance that composes a protoplasmic individual forms an indiscerptible whole. It is essentially a chemical unit, for all its constituent parts are held together by most specific bonds of chemical union. Its interdependent vital activities obviously contradict the prevalent notion, that it is composed of a mere aggregate of separate molecules. Such an aggregate of autonomous elements could nowise, save by miraculous intervention, co-operate in effecting the unitary movement of life. Only a substance forming a chemical whole, a substance whose component parts are integrant, and not merely aggregated constituents, can possibly display the manifoldly related, yet indivisible, molecular activity in which life consists. Each of the numberless kinds of amœboid beings assumes a distinct adult form. This clearly indicates that its growth is controlled by the nature of the individual as a whole. It can never be the outcome of the mere cohesive aggregation of a set of chemically non-interdependent molecules. The flow of a protoplasmic process, nay, of an entire protoplasmic individual, in consequence of cumulative reintegration, demonstrates visibly the chemical interdependence of the constituent parts. And so does likewise their shrinking on stimulation. Let the all-pervading bond of chemical union snap, and the material which even now composed the living individual will no longer be a living substance, but a mere deadened lump of organic stuff, rapidly deteriorating into less and less complex fragments of its former self.[1]

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[1] What complicates the molecular process underlying vitality, is that each particle of deteriorated protoplasm serves as restitutive material for other deteriorated particles, just the same as food. Two disintegrated processes, for instance, meet

Be it emphatically repeated: every interpretation of life, which makes the unitary activity in which it consists be performed by a number of separate chemical units of whatever kind, gemmules, physiological units, plastidules, biophores, somacules, and eventually cells; every such mere aggregative interpretation is thereby fatally vitiated at its foundation, and logically forced to invoke miraculous help, in order to actuate and regulate the organic co-operations of so many milliards of separate beings. Strange that the eminent scientific thinkers who have occupied themselves with this question have failed to recognise so patent a state of things.[1]

In illustration of the central fact, that the fundamental and indivisible molecular activity of vital disintegration and reintegration determines not only the mass-motion or motility of the living indi-

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and coalesce by force of such restitutive affinity. So in gradually dying protoplasmic individuals restitution by means of complemental combination of different portions of the protoplasm goes along with its eventually fatal disintegration. This happens when the conditions that cause disintegration preponderate. When, on the contrary, even after profound disintegration, the restitutive conditions gain the ascendency the individual recovers gradually its full integrity through combination with complemental material derived from the medium. All this is readily and most strikingly observed in artificially slicing protoplasmic individuals.

[1] So far as "cells" are concerned, the continuity of their protoplasm, and its importance as a clue to the understanding of the unity of the organic individual, is being more and more fully recognised by leading biologists.

"Nach dem Mitgetheilten kann nicht, wie es nach den älteren Anschauungen der Fall sein sollte, der Körper als ein blosses Conglomerat von Zellen angesehen werden, die durch ihre Membranen völlig von einander abgeschlossen und in ihren Existenzbedingungen ziemlich unabhängig von einander sind, es bestehen vielmehr in den Geweben und Organen so zahlreiche Verbindungen zwischen gleichartigen und ungleichartigen Zellen, dass es vollkommen gerechtfertigt ist, den ganzen Körper als eine einheitliche Masse lebender Substanz, als ein Synplasma aufzufassen." *Real-Encyclopädie der gesammten Heilkunde*, Professor Karl Frommann, Article 'Zelle,' 1890.

"Bis vor Kurzem nahm man an, dass die Plasmakörper der Pflanzenzellen durch die Zellwände vollständig getrennt seien und in keinem Zusammenhang mit einander stehen. Man musste sich fragen, wie ein Zusammenwirken einzelner Zellen im Dienste des Gesammtorganismus unter solchen Umständen möglich sei und die Pflanze als Lebenseinheit dabei zu Stande komme. Dieses Problem fand seine Lösung in der Entdeckung, dass die einzelnen Plasmakörper der Zellen durch feine protoplasmische Fäden verbunden sind. Diese feinen Fäden durchsetzen die Wände, reichen von Zelle zu Zelle und bedingen in solcher Weise, dass die lebendige Substanz einer Pflanze thatsächlich zusammenhängt, dass somit die Pflanze, ähnlich wie das Thier, einen einheitlichen, lebendigen Organismus bildet." Prof. Eduard Strasburger, *Rede zum Antritt des Rektorates, etc.*, 1891.

vidual, but also its essential form, as well as its main functions, ectodermic, entodermic, and depurative, together with the definite position of the special portions of protoplasm that carry on these functions; in illustration of this cardinal fact let us examine the highly developed, yet out and out fluent, protoplasmic individual, Fig. 3.

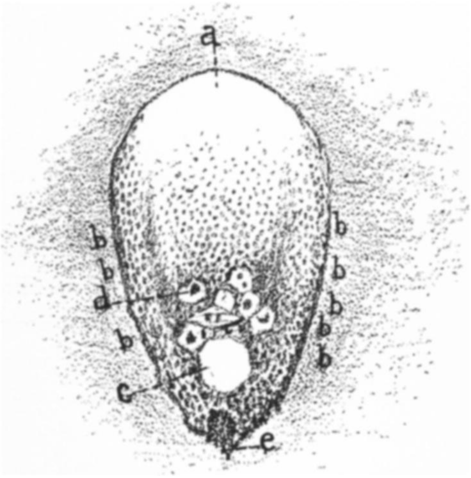

Fig. 3.—An Ovoid Amœba.
a. Hyaline material issuing from granular matrix.
b. Disintegrated protoplasm-forming envelope.
c. Depurative vesicle.
d. Food deposit.
e. Undigested food-residue.

A clearly outlined ovoid being is seen to flow evenly across the field of the microscope. It may be detected at a glance that it embodies all essential features of organisation, but organisation not yet structurally fixed. Though throughout fluent, it maintains a definite shape. It is bilaterally symmetrical. It has an oral and an aboral pole, an incipient ectoderm, a digestive entodermic substance, a depurative vesicle; all occupying definite positions determined by the indivisible cycle of activities that constitute its vitality. It takes in food only in front, retains it until digested in the centre of the body, and eventually evacuates the residue at the aboral pole.

Much of the scientific mystery attaching to vitality and organisation will be dispelled on attentively watching their manifestations in this most favorable protoplasmic specimen. We have here a living being consisting of nothing but fluent substance, exhibiting a localised distribution of all essential vital functions. It constitutes a veritable vortex of vital activity, maintaining amid constant molecular change its original constitution; advancing, moreover, steadily headforemost through space. All the differently functioning regions of this vital vortex receive their specific character from the peculiar position they occupy in the cycle of molecular activity that constitutes living substance.

From the neighborhood of the digesting protoplasm within the body there issues a continual flow of finely granulated material; and farther in front there emerges from this granular matrix a perfectly hyaline substance. This foremost product of cumulative integration presents thus an expanding surface to the medium. Suffering at last disintegration, it is thrust aside by the bursting forth of new expanding material and slides down along the outer surface, helping there to form the gradually contracting envelope; closing in, at last, in the rear completely collapsed, and ready to re-enter by means of complemental restitution the ascending current. It is by means of this cycle of definitely interdependent activities that the form of the organism is maintained. Food coming in contact with the substance in front gets wrapped up in a coat of protoplasm and is lodged with the same as a nutritive corpuscle in the centre of the body.[1] Between the disintegrated protoplasm gathered in at the rear and the stationary deposits of nutritive corpuscles, generally one single depurative vesicle ministers both to functional and to nutritive depuration.

This beautiful and highly instructive organism has to be looked upon as forming one single process, through the apex of which a renewed flow of hyaline material is ever maintained. In this manner only is its steady locomotion effected. This is visibly demonstrated, and all other attempted explanations of amœboid motility are therefore erroneous.

It is evident that the apex, and after it the circumference are the chemically most complex parts of the protoplasmic individuals. And it is no mere coincidence that in highly developed organisms their surface is found to consist of the most essential organic structures. These have been formed so as adequately to respond to the sundry stimulating influences of the medium. The headmost part of the living substance may well be said to represent the consummation of all the vital labor performed within the living individual. It is, therefore, intrinsically best fit to enter into higher relations with the stimulating influences. It is in fact an incipient head.

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[1] In the course of protoplasmic elaboration one portion directly combining with food and lodged inside the body comes to prepare restitutive material for another portion which is thereby enabled to assume exclusively the dynamical relations with the medium. In this manner a digesting part of the common protoplasm becomes subservient to a moving and functionally stimulated part; the entoderm subservient to the needs of the ectoderm.

As regards the power of vital reproduction, the marvel of marvels of organic nature, its most primitive modes of occurrence will allow us to penetrate its secret to some extent. The fact that a protoplasmic individual has to be looked upon as a chemical unit, which on disintegration tends to restore its full integrity by means of combination with complemental material, gives us the clue to the secret of reproduction.

Growth has then to be conceived, not as a mere multiplication of separate organic molecules, but as the gradual reintegration of a fragment derived from an adult organism. This, in fact, is unmistakably demonstrated in the reconstruction of specifically formed adult shapes from artificial sections of the same. Also, normally, in fissiparous division, where the upper half of a dividing individual has to reconstruct its lower half, whilst, *vice versa*, the lower half is reconstructing its upper half. How, short of miraculous intervention, could any sort of mere multiplication and aggregation of separate molecules ever accomplish such a feat? A reproductive germ is essentially a chemical fragment of the adult organism, which by force of its most specific indwelling affinities has power to reconstitute itself to full integrity.

The interpretation of the fundamental facts of vitality and organisation here given may be found serviceable as a means of unravelling the scientific difficulties of complex organisation.[1] Investigators, who in future will thread their way through its labyrinthine intricacies by help of this clue, may be less likely to lose their bearings.

EDMUND MONTGOMERY.

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[1] This has been attempted by the present writer in the case of Infusoria, "Ueber das Protoplasma einiger Elementar-Organismen" (*Jenaische Zeitschrift für Naturwissenschaft*, Bd. XVIII, N. F. XI); and also in explanation of muscular activity, "Zur Lehre von der Muskelcontraktion" (*Pflüger's Archiv f. d. gesammte Physiologie*, Bd. XXV, 1881).